only the high frequency of the pulses, not the intended low frequency. For example, the bursts can be limited to a particular percentage (e.g. 20%) of the period of the desired low frequency waveform.

[0073] In practice, it may be desirable to pick a frequency that is high enough that a few full cycles can easily be included in the burst. For example, an 80 Hz signal can be used. This would allow four full cycles to be imparted within only 50 milliseconds. If this technique were to be used to convey a 1 Hz tactile effect, the signal used to drive the mass would have a 50 millisecond burst of the 80 Hz signal, where 950 milliseconds is provided between bursts. The resulting tactile feel is much stronger to the user than a simple 1 Hz square wave.

[0074] The bursts need only be used at low frequencies to convey greater strength tactile sensations. At higher frequencies, the bursts are not needed since the sensations are stronger. Furthermore, as the commanded frequency increases, the bursts may run too closely together and thus convey only the high frequency of the burst to the user, rather than the commanded lower frequency. Thus, a threshold frequency can be established, under which bursts are used, and over which bursts are not used and the commanded frequency is directly output.

[0075] In other embodiments, the high frequency bursts described above can be output at irregular or nonperiodic intervals. For example, a particular gun may have two closely-spaced bursts followed by three widely-spaced bursts. These five bursts can be defined in a waveform of a particular duration. The defined waveform can also be repeated, if desired, or started again from a selected point in the duration of the defined waveform.

[0076] **FIG. 5***c* is a graph **220** illustrating an alternate drive waveform **222** of the present invention for providing higher strength low frequency tactile sensations. In this embodiment, the drive signal can settle at the extreme amplitudes of the signal, as shown, rather than settling at zero as shown in **FIG. 5***b*.

[0077] Resonance

[0078] Another way to increase the strength of tactile sensations provided by an oscillating mass is to drive the actuator at a resonant frequency of the harmonic system. Like any spring-mass harmonic system, the actuator assembly and housing of the device can be excited at a resonance frequency and yield maximum output for a given input using the physical resonance properties of the mechanical system. This physical amplification can be harnessed for additional efficiency in conveying tactile sensations.

[0079] For example, when an interface device **12** is designed, the properties and dimensions of the housing, actuator assembly, and other components can be made a certain way to provide one or more particular resonance frequencies in the mechanical system. The strongest sensations of the device are typically those having a frequency near the resonant frequency(ies). Other aspects of tuning a resonant frequency system are described in copending patent application Ser. No. 09/675,995, incorporated herein by reference. Some embodiments may only be able to approximately provide oscillations at a desired resonance frequency, due to unavoidable tolerances in manufacturing that may cause changes in the resonance frequency of the mechanical system.

[0080] In one embodiment of the present invention, the pulse bursts described with reference to **FIGS. 5***b* and **5***c* can be used with the resonant frequency described above. For example, the frequency of the bursts **214** or **224** can be provided at or near the designed resonance frequency of the mechanical system.

[0081] In such an embodiment, it may be important to provide enough cycles of the resonance frequency in the burst to allow the inertial mass to approach its maximum acceleration. For example, this can be three cycles. For example, if a very strong 1 Hz tactile sensation is desired for a tactile mouse with actuator assembly **100** and a resonance frequency of 40 Hz, a strong sensation can be achieved by providing a 75 millisecond burst at 40 Hz, where the burst repeats every 1000 milliseconds, or 925 ms between bursts. The end result is a 1 Hz sensation that is many orders of magnitude stronger than if the mass were driven directly by a 1 Hz square wave.

[0082] If this combined method is used, it may be desirable to tune the resonant frequency of the actuator assembly and mechanical system upwards. A higher resonant frequency allows shorter bursts to be used for the same number of cycles. Shorter bursts are more versatile than longer ones because shorter bursts can be used to emulate higher frequency sensations.

Superimposing Low Frequency Sensations and High Frequency Sensations

[0083] Low and high frequency sensations can be superimposed as described herein for at least two purposes. One purpose is to provide a desired low frequency sensation that is perceived much more strongly to the user than if the low frequency waveform were directly used to drive the actuator assembly **100**, similar to the reasons for using the method described above with reference to **FIGS. 5***b* and **5***c*. Another purpose is to combine two (or more) tactile sensations, where the magnitude of the combined tactile sensation is not appreciably attenuated by the limited range of the inertial mass of the actuator assembly. The techniques described herein can achieve these desired results.

[0084] Strong Low Frequency Sensations

[0085] Strong low frequency sensations can be output using the present method. In a different embodiment from the pulse burst embodiment described above, a commanded low frequency sensation can be superimposed with a "dummy" high frequency signal to provide stronger low frequency sensations to the user. In basic terms, a high frequency waveform is output to provide the stronger tactile sensation to the user, but the high frequency waveform is modified or modulated according to the desired low frequency so as to convey the sense of the low frequency in the tactile sensation perceived by the user.

[0086] **FIGS. 6 and 7** are graphs **250** and **252**, respectively, illustrating a first method of superimposing high and low frequency waveforms to provide a greater-strength low frequency sensation. In **FIG. 6**, two signals are shown, a signal **254** at the commanded (desired) frequency, and a signal **256** at a higher frequency. In this embodiment, the signal **254** having the desired low frequency is added to the high frequency signal **256** that is created specifically for the present method. The high frequency signal **256** can be at any